The existing Columbia and Snake River systems exceed the water quality criteria for temperature frequently throughout their lengths. However, the water quality standards of Oregon and Washington and the Colville Tribe state that the criteria are not to be exceeded due to human or anthropogenic activities. We have already shown that the water quality criteria were exceeded at Rock Island Dam and Bonneville Dam when they were the only dams on the Columbia River (figures 3-1 and 3-2). Assuming that the water temperatures at those dams when they were the only dams on the river are indicative of the temperatures in the absence of human activities (the site potential temperatures) we can compare that temperature record to the existing river temperatures to see if the temperature regime has been altered.

Bonneville Dam is the dam furthest downstream and is most likely to demonstrate any cumulative impacts on water temperature from the dams and other human activities upstream. Figure 3-12 provides information on the number of days that exceeded water quality criteria at Bonneville Dam. It compares two time periods: the eighteen years when Bonneville was the only dam on the river for 300 miles with the first eighteen years following construction of the last dam on the Columbia/Snake River System. The figure demonstrates a considerable increase in the number of days per year that criteria are exceeded. The mean number of days exceeding the criteria is four times greater (48.4 days versus 12.3 days) for the time frame after all the dams were constructed. Figure 3-13 shows the same information in a different way. The frequency of exceedance of the criteria was about 3% of the time during the period when Bonneville was the only dam for 300 miles and 13% of the time after all the dams were constructed.

Figure 3-12. Number of Days that exceeded 20 Deg C at Bonneville: Comparison of the two periods 1939-1956 and 1976-1993.

Figure 3-13. Frequency of Exceedance of 20 Deg C at Bonneville Dam for the two periods 1939-1956 and 1976-1993.

Figures 3-12 and 3-13 show that a difference exists in the number of days exceeding water quality criteria between the two time periods 1939-1956 and 1976-1993 but they do not explain the cause of the difference. It may be due to the presence of the dams and human activity or it may be due to other physical differences during the two time periods. The most obvious physical characteristics that govern water temperature are air temperature and flow in the river. Davidson (1964) reported that weather and river flow accounted for 81% to 85% of the variability in water temperature in the free flowing Columbia River at Rock Island Dam.

Figures 3-14 and 3-15 compare air temperature and flow for the two time periods. Figure 3-14 portrays the annual average of the maximum daily air temperatures at Goldendale, WA for the two time periods. The summary statistics for these data for the two time periods are:

	1939-1956	1976-1993
Maximum	65.08 F	63.09 F
Minimum	57.67 F	57.84 F
Mean	61.20 F	60.69 F

Figure 3-14. Annual Average of the Maximum Daily Air Temperatures at Goldendale, WA for the Two Periods 1939-1956 and 1976-1993

From visual examination and the summary statistics, the average annual air temperatures from the two periods do not appear to differ substantially. A two-tailed Student's T Test confirms this. The probability that rejecting the null hypothesis would be wrong, as calculated by the T-Test, is 40%. Generally, for two sets of data to be considered different the probability is 10% or less.

The annual average of the daily average Columbia River flows at Grand Coulee for the two time periods are shown in figure 3-15. The summary statistics for these data for the two time periods are:

	1939-1956	1976-1993
Maximum	136298.4 CFS	132641.5 CFS
Minimum	71147.5 CFS	80343.0 CFS
Mean	110150.8 CFS	102136.3 CFS

Figure 3-15. Annual Average of the Daily Average Flows at Grand Coulee for the Two Periods 1939-1956 and 1976-1993.

From visual inspection and the summary statistics there does appear to be somewhat more difference for flow than for air temperature. The probability that rejecting the null hypothesis would be wrong, as calculated by the T-Test, is 20%.

Neither air temperature nor river flow are significantly different between the two time periods and do not appear to account for the large increase in the number of days in which water temperature exceeded 20 deg C. Davidson (1961) predicted that the dams on the Upper Columbia would increase the temperature of the river. During hot, dry summers he expected that the river temperature would increase as much as 5 degrees F in July and August and 1.5 degrees F in September between Chief Joseph Dam and Priest Rapids Dam.

In order to better understand the influence of air temperature and river flow on the number of days that water quality criteria are exceeded at Bonneville Dam in the two time periods 1939-1956 and 1976 to 1993, the number of days in which air temperature exceeded 90 degrees F and 80 degrees F and the number of days that river flow was less than 50,000 CFS and 40,000 CFS were computed. Table 3-6 shows the results of this analysis.

Table 3-6. Comparison of the number of days per year that water temperature exceeded 20 degrees C, Air Temperature exceeded 90 Degrees F and 80 Degrees F and Columbia River Flow exceeded 50,000 CFS and 40,000 CFS for the two Time Periods 1939-1956 and 1976-1993.

	# Days water temp > 20 deg C		**# Days Air Temp > 90 deg F**		**# Days Air Temp > 80 deg F**		**# Days River Flow < 500000 CFS**		**# Days River Flow < 400000 CFS**	
	1939-1956	1976-1993	1939-1956	1976-1993	1939-1956	1976-1993	1939-1956	1976-1993	1939-1956	1976-1993
Max	41	70	31	33	89	83	211	54	103	22
Min	0	3	3	0	41	49	5	0	0	0
Mean	12.3	48.4	17.7	18.44	64.3	63.8	86.17	13.5	35.28	3.72
St Dev	10.96	16.04	8.11	9.42	13.51	9.95	67.84	15.94	41.7	5.75
Varianc	120.23	257.43	65.86	88.7	182.47	99.04	4601.9	193.9	1738.7	33.03

Note that there is very little difference in the number of hot days per year in the two periods, the difference in the average number of days over 90 degrees F and 80 degrees F both being less than one day. There was a considerable difference in the number of low flow days/year during the two periods with the second time period averaging almost 73 fewer days with less than 50,000 CFS and almost 32 fewer days with less than 40,000 CFS. This indicates that differences in air temperature and river flow do not account for the differences in number of days during which water temperature exceeds 20 degrees C. Figures 3-16 and 3-17 show the number of days that water quality criteria are exceeded at Bonneville Dam in the two time periods 1939-1956 and 1976 to 1993, the number of days in which air temperature exceeded 90 degrees F and the number of days that river flow was less than 40,000 CFS. Only 90 degrees and 40,000 CFS were graphed to minimize confusion in the graphs.

1939-1956 **1976-1993**

Figure 3-16: Comparison of the Number of Days Per Year that Water Temperature Exceeded 20 Deg C and Air Temperature Exceeded 90 Deg F for the Two Time Periods 1939-1956 and 1976-1993

Figure 3-16 shows that there is some degree of correlation between days exceeding water temperature of 20 Deg C with days exceeding air temperature of 90 Deg F in both time periods, but for the second time period, after the dams were constructed, the relationship exists at a much greater number of days over the criterion. The correlation coefficients are 0.68 for 1939-1956 and 0.45 for 1976-1993. Something other than air temperature is a significant factor in the difference between the number of days/year that exceed 20 Degrees C during the two time periods.

1939-1956 **1976-1993**

Figure 3-17: Comparison of the Number of Days Per Year that Water Temperature Exceeded 20 Deg C and River Flow was less than 40,000 CFS for the Two Time Periods 1939-1956 and 1976-1993

Figure 3-17 shows that water temperature and river flow interact similarly to water temperature and air temperature. In the first time period before the dams were built there was a relationship between the number of days exceeding 20 degrees C and the number of low flow days with a correlation coefficient of 0.45. In the second period there was no defined relationship, the correlation coefficient being 0.02.

Table 3-7 lists the correlation coefficients for all four tests: number of days with water temperature over 20 degrees C tested against number of days with 1) air temperature over 90 degrees F, 2) air temperature over 80 degrees C, 3) river flow less than 50,000 CFS and 4) river flow less than 40,000 CFS. Table 3-8 lists the multiple regression statistics for the same 4 tests. Note that before the dams were constructed the strongest correlation was with test # 1, days over 90 degrees C air temperature. But after the dams were constructed, test #2, days over 80 degrees F air temperature, became more important. Both of the flow tests had smaller correlation coefficients after the dams were built. Similarly, table 3-8 shows that before the dams were built, test #1, number of days with air temperature over 90 degrees F accounted for most of the days over 20 degrees C water temperature. The coefficient was 0.929 and the P value was 0.039. After the dams were constructed, test #2, days over 80 degrees F air temperature had the highest coefficient, 0.627 and accounted for more days over 20 degrees C water temperature than test #1.

This is another illustration of the effects of the dams on water temperature. The dams make the cooler summer days (eg days over 80 degrees instead of days over 90 degrees) more important in determining water temperature. The very hot days are less important. There are two reasons for this. First, water particles in the impounded river are subjected to the air temperature for a longer time because travel time in the river is much slower. Second, the very hot days warm the impounded water much less because its volume is much greater. There are more cooler summer days. That is, there are more days with air temperature greater than 80 degrees than there are with temperature greater than 90 degrees. So with the dams in place they become much more important in determining water temperature.

Table 3-7: Correlation coefficients for four tests: water temperature over 20 degrees C tested against number of days with 1) air temperature over 90 degrees F, 2) air temperature over 80 degrees C, 3) river flow less than 50,000 CFS and 4) river flow less than 40,000 CFS

	Air > 90 Deg F	**Air > 80 Deg F**	**Flow < 50K CFS**	**Flow < 40 K CFS**
1939 - 1956	.681	.509	.256	.310
1976 - 1993	.450	.535	.026	.028

Table 3-8: Multiple Regression Statistics for four tests: water temperature over 20 degrees C tested against number of days with 1) air temperature over 90 degrees F, 2) air temperature over 80 degrees C, 3) river flow less than 50,000 CFS and 4) river flow less than 40,000 CFS. The Multiple R squared for the regressions were 0.487 for 1939-1956 and 0.328 for 1975-1993.

	Air > 90 Deg F		**Air > 80 Deg F**		**Flow < 50K CFS**		**Flow <40 KCFS**	
	Coefficient	**P Value**	**Coefficient**	**P Value**	**Coefficient**	**P Value**	**Coefficient**	**P Value**
1939 - 1956	.929	.039	.114	.726	.036	.549	.002	.980
1976 - 1993	.448	.413	.627	,205	.399	.581	-0.76	.656

Clearly some factors other than air temperature and river flow are contributing to the increased number of days during which water quality criteria are exceeded after the dams were built. There are other meteorological factors in addition to air temperature that have a role in water temperature. Wind speed, cloud cover and snow pack are probably important. The data are unavailable to evaluate all of these parameters, but air temperature and river flow provide a good estimation of the relation between meteorology and water temperature. Air temperature reflects cloud cover and solar radiation and river flow reflects snow pack and precipitation.

The data showing that the number of days during which water temperature exceeded the water quality criteria increased 4 times after all the existing dams were built is a strong line of evidence that the dams have resulted in significant changes to the thermal regime of the Columbia River.